Report for the MERIT overseas program

Graduate School of Frontier Sciences Department of Advanced Materials Science, D1
Roppongi Masaki

Overview

I stayed at the University of British Columbia (UBC) in Canada from 12th June to 23rd July 2022 and did muon spin rotation resonance (μSR) experiments at TRIUMF. We also participated in the international conference M^2S (The International Conference on Materials and Mechanisms of Superconductivity & High-temperature Superconductors) held in Vancouver from 18th to 22nd July and gave an oral presentation. This report describes these details.

μSR experiment at TRIUMF, University of British Columbia

In our group, we have been studying the mechanism of superconductivity in unconventional superconductors and new superconducting states on various superconductors. Among them, time-reversal symmetry-breaking superconductivity is a type of topological superconductivity that has attracted much attention in recent years because of its potential application to quantum computers. And iron-based superconductors, one of the main research topics of our group, are one of the unconventional superconductors that exhibit high-T_c superconductivity as cuprate. They have been studied over the past decade as materials with various phases such as magnetism, topological properties, and electronic nematic phase (where electronic symmetry breaks the rotational symmetry of the lattice system). Recently, time-reversal symmetry-breaking superconducting states in some iron-based superconductors have been reported, which are very interesting.

Fig.1 Photo with collaborators at TRIUMF

The μSR uses elementary particles "muon" to capture the magnitude and fluctuations of the internal magnetic field in materials sensed by muon spins. It is also possible to detect minute spontaneous magnetization caused by time-reversal symmetry breaking in the superconducting state. In fact, our group has previously performed experiments using the μSR method on the iron-based superconductors FeSe and Fe (Se, S) and succeeded in detecting the internal magnetic fields due to time-reversal symmetry breaking in the superconducting state. Furthermore, the magnetic penetration depth measurement by Transverse magnetic field (TF)-μSR was performed to compare the change in superfluid density between FeSe and Fe(Se, S), and it was found that a part of the Fermi surface remains in the superconducting state of Fe(Se, S). It suggested that a new superconducting state called "Bogoliubov Fermi surface", which has been proposed theoretically in recent years, has been realized.

In this study, we have performed experiments on Fe(Se, Te) using the μSR method. Our group has succeeded in synthesizing high-quality single crystals of Fe(Se, Te) in the low Te-substitution region. So, in order to confirm whether the novel superconducting state is realized in Fe (Se, Te) as like on Fe(Se, S), we performed the following experiments.

In the first measurement, we did measurements up to 2-100 K at beamline M20 from 14th to 19th June. We performed measurements on the $FeSe_{0.7}Te_{0.3}$ samples, but in the first measurement we saw little signal due to the small amount of sample. After that, we added samples of the same composition and were able to detect signals, and in particular, in Zero magnetic field (ZF)-μSR measurements, we succeeded in detecting an internal magnetic field due to time-reversal symmetry breaking superconducting state in $FeSe_{0.7}Te_{0.3}$. The magnetic penetration depth was obtained from TF-μSR measurements, which gives the temperature dependence of the superfluid density, and the results suggest that the $FeSe_{0.7}Te_{0.3}$ indicated that superconducting gap structure is fully gapped *s*-wave superconductivity. Next, measurements up to 20 mK-8 K (16 K) were performed at beamline M15 from 5th to 12th of July using a dilution refrigerator. In the experiments at M15, the sample is attached to a silver plate to ensure heat conduction to the sample, which results in a very large background. It is also very difficult to detect spontaneous magnetization from ZF-μSR measurements due to the influence of the residual magnetic field caused by the superconducting magnets attached to the dilution refrigerator. Therefore, M15 mainly measured TF-μSR. In M15, TF-μSR measurements were performed on three samples with compositions of $FeSe_{0.3}Te_{0.7}$, $FeSe_{0.7}Te_{0.3}$, and $FeSe_{0.4}Te_{0.6}$ in the order in which the measurements were performed. As a result, we obtained temperature dependence suggesting a full-gap s-wave superconducting state in all these samples. Detailed analysis and discussion of these results are underway at the time of writing this report, and will be summarized in a paper after additional experiments are conducted.

Outside of our group's machine time mentioned above, we participated in discussions and measurements of other groups. Other group's measured materials included the charge-ordered Mott insulator $Ba(Co, Ni)S_2$, the Kagome magnet $(Co, Fe)_3S_2Sn_2$, and the ferromagnetic Mott insulator (Y, Ca)TiO_3, which provided a good opportunity to learn physics in a system different from the one our group studies for me. In addition, I had little experience in discussions in English before my stay and lacked confidence, but during this stay, I had many discussions and was able to express my opinions and questions more accurately in English, which gave me confidence in English discussions.

Participation in the international conference M^2S

The International Conference on Materials and Mechanisms of Superconductivity & High-temperature Superconductors (M^2S) was held from 18th to 22nd of July Vancouver Canada Place, Vancouver, Canada. In this presentation, I gave an oral presentation on the results of my research on superconducting symmetry in Kagome lattice superconductivity. In my case, my master's course was for the period most affected by COVID-19, so this was the first time I had attended on-site, as all the conferences I had attended had been held online. So, the presentation itself was quite nerve-wracking, but I managed to pull it off. The most exciting part was that after my presentation, I received good reactions from various other researchers and was able to discuss my results with them in situ. In addition, I was able to fully enjoy an on-site international conference, such as being able to talk directly to other participating professors and researchers about the research I was interested in, ask questions and discuss issues, and interact and exchange information with students and researchers from various countries.

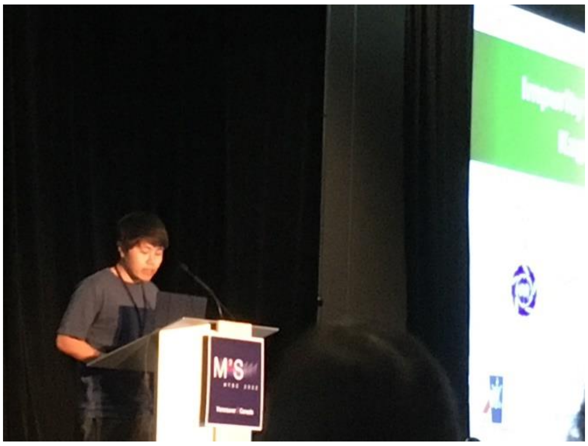

Fig. 2　Presentation at M^2S (by the author)

Living and research environment in Vancouver

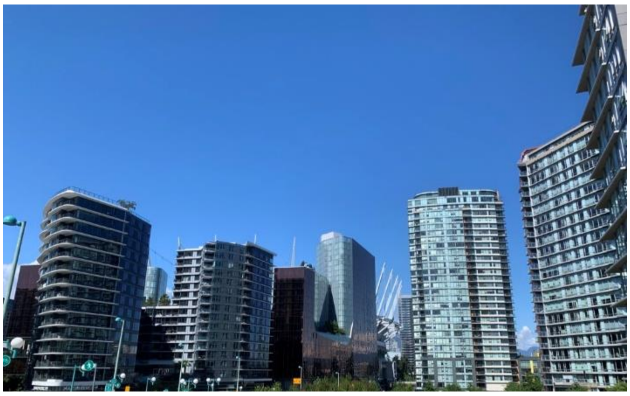

Fig.3 Vancouver Downtown

Although I had never stayed abroad for a long period of time, I felt that Vancouver was a very comfortable place to live in many aspects, as people of many different nationalities lived here. UBC has restaurants for a variety of national dishes, supermarkets, and medical facilities, etc…, all located on campus, so the campus is like one big city. Public transportation is well developed by buses and trains, and downtown is relatively easy to access. In addition, it has a very rich nature, and the daytime is very long in summer, the climate is very comfortable. So, many people are engaged in sports, cycling, and outdoor activities. One of the major differences from Japan is that most people in Vancouver finish their work around 5 p.m. and spend their free time in the evening, which seems to be more relaxed than in Japan. However, the only disadvantage was the extremely high cost of living (coupled with the weak yen).

The research environment also differed greatly from that in Japan. In addition to TRIUMF, I visited the Stewart Blusson Quantum Matter Institute (SBQMI) at UBC. The biggest difference is that there is almost no separation between each group. In fact, at SBQMI, various people from different laboratories come and go from a single room, and I felt that it is an environment where it is easy to communicate with people from other fields. In Japan, a single faculty advisor is assigned to each student to conduct research, but at UBC and in other countries, research is often conducted under the guidance of multiple professionals in a collaborative research style. In addition to horizontal connections, the concept of hierarchical relationships based on age (although there are naturally differences in position) seems to be almost non-existent, and I found it very attractive that vertical connections are easy to form and that discussions can be held in a flat manner. This kind of framework-free thinking may be difficult to achieve in Japan, but it is very important no matter where I do research in the future, and I felt that I would like to cherish what I experienced this time. The difference in terms of funding is also very apparent: at SBQMI and TRIUMF, there is a lot of expensive experimental equipment, etc…, and researchers in China and Canada are given much more funds for individual research than those in Japan. Thus, I must consider what kind of research we should conduct with a limited budget if I want to conduct research in Japan in the future.

Thus, during my stay at UBC and during the international conference, I was able to talk to researchers from various countries, which was very helpful in considering my future career plans.

Acknowledgments

I would like to express my gratitude to the many people who assisted me in this long-term overseas study program.

First, I would like to thank my supervisor, Prof. Takasada Shibauchi, for suggesting this plan. And I would also like to thank Prof. Yasunobu Nakamura, my advisor in the MERIT-WINGS program, for recommending me for this long-term overseas study program.

I received great support for this dispatch from Prof. Yasutomo Uemura from Columbia University. Prof. Uemura has been of great help in arranging beamtime and experiments for TRIUMF, discussing our results, and providing financial support. Prof. Kenji Kojima, Dr. Yipeng Cai, and Dr. Guoqiang Q. Zhao have been especially helpful in the TRIUMF experiments and my life at UBC. I am especially grateful to Prof. Kojima and Dr. Yipeng for not only helping us in my time of need but also for taking us sightseeing and out to eat on numerous occasions. Dr. Guoqiang also very kindly guided us through the process of the experiment and analysis of the results. Moreover, during my stay at TRIUMF, I had the opportunity to communicate with many people, including Ms. Marta-Villa de Toro Sanchez, Mr. Cyrus Young, Dr. Mohamed Oudah, Mr. Eric Seewald, Mr. Dhruv Kush, and Mr. Issam Khayr, which I found very meaningful. Mohamed guided us to visit SBQMI and provided us with a very useful opportunity. In addition, I would like to thank the TIRUMF staff for all their help and support. I would especially like to thank Dr. Bassam Hitti for helping me set up the temperature control system for the experiments up to high temperatures in M15.

In these experiments, not only I but also Mr. Koki Ogawa and Mr. Supeng Liu who are in the same Shibauchi group participated and provided a lot of assistance. FeSeTe high-doped samples were provided by Prof. Takao Watanabe from Hirosaki University, Prof. Yoshikazu Mizuguchi, and Assistant Assistant Prof. Aiti Yamashita from Tokyo Metropolitan University. At this time, we were very rushed about the preparation of samples, which caused us a great deal of inconvenience, and we are constantly grateful that they managed to prepare single crystals. I would also like to thank all of them for the discussions and exchanges during the international conference.

This stay was a very meaningful experience for me. I would like to thank everyone.